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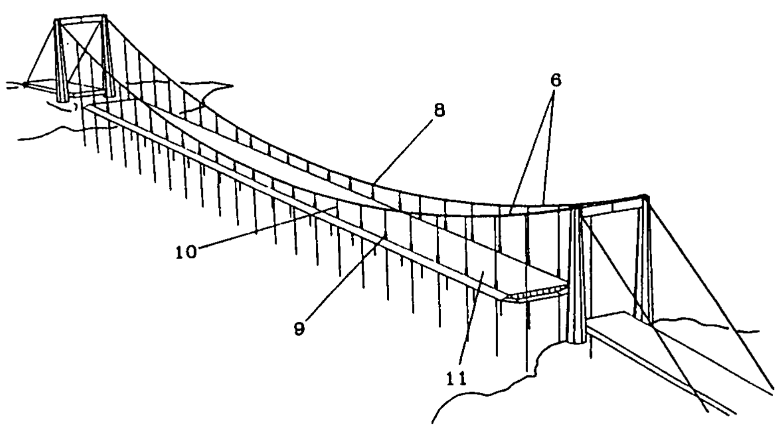
(54) Title: METHOD FOR BUILDING SUSPENSION BRIDGES



(57) Abstract

A method for constructing and assembling a suspension bridge with main girder of steel, aluminium or concrete (11) suspended by hanger cables or hanger rods (15) from suspension cables or suspension rods (6). The bridge girder is fabricated in one piece or in bridge girder elements larger than the distance between two hanger cables or hanger rods (15), and the bridge girder (11) is brought and positioned under the suspension cables (6) at surface level and elevated in a controlled manner into the bridge span to its final elevated position, and the bridge girder (11) is locked to the hanger cables or hanger rods (15).

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METHOD FOR BUILDING SUSPENSION BRIDGES.

The present invention relates to a method for constructing and assembling suspension bridges, and in particular suspension bridges with bridge girders in steel, aluminum or concrete. The invention will allow cost effective fabrication and erection of the bridge from one complete bridge girder, or a few prefabricated and outfitted bridge girder elements.

The known methods (fig. 1 and 2) in suspension bridge building involves erection of the bridge in small bridge girder elements by the use of either a cable crane running on the suspension cables or by using a floating crane.
The reason for the assembly of the bridge girder from a number of small sections with lengths varying from 12 to 36 meters is the suspension cable and hangers ability to support the forces in the hangers, the bending moment in the girder element and the bending of the suspension cables over the hanger clamps created by the weight and length of the girder sections.

It has therefore up till now been necessary to prefabricate a number of short girder sections which are try-fit on the ground level, transported to the site, lifted into the span and temporarily loosely bolted together until about 70% of the bridge span has been completed.

At this point the bridge girder and suspension cable geometry, which has undergone a continuous change during the installation of girder elements, will now be so close to the geometry of the finished bridge span that welding of the girder sections may start, and the bolts removed.

It is important to realize that the suspension cables (6) should have a parabolic geometry when the bridge is complete, and the bridge girder an arch geometry when installed.

Therefore the hangers are made up in different but fixed lengths with no or few possibilities of length adjustments.

The design, construction and erection of suspension bridges has hence been limited inter alia by the limitations in fabrication environment as well as logistics, erection technology and the ability to control the geometry and forces of the suspension cables during girder installation.

The restrictions above will force the designer and constructor to perform most of the construction on the building site and up in high altitude, exposed to the weather and with great risk. As a consequence, the productivity suffer significantly, so will the quality, the execution time and the cost.

The present invention makes it possible to fabricate the bridge girder on the ground level, preferably in a yard, without any of the limitations mentioned above.

The construction method will therefore open up for a near complete prefabrication of the bridge span under cover and under controlled atmospheric conditions. The bridge girder may be fully outfitted with rails, light masts, electric wiring, painted etc. before transport to the erection site. As the fabrication of the bridge girder takes place under cover, it will also allow the use of other materials like aluminium, which will reduce the weight and later maintenance of the girder.

If there are restrictions in the yard, load-out facilities, transport or infrastructure, it might be advantages to fabricate and outfit the girder in largest possible sections.

Unlike the present methods, the invention makes it possible to fabricate and install girder sections longer than the length between two hanger cables. This is vital, as long and

outfitted sections will reduce work on site and assembly in the span.

By using this kind of design and fabrication philosophy, the productivity will be improved, the site team will be reduced, the project execution time will be reduced, and so will the cost. For the client, the combined reduction in cost and shorter delivery time will improve his cash flow and net present value significantly. At the same time, the safety of men and the safety in the delivery time will be improved, and so will the quality of the product.

The present invention will allow full control and adjustment of the suspension cable geometry at the same time as it opens up for lifting of section weighing 500 to 5000 metric tonnes and section lengths of 50 to 1000 meters.

It is important to be aware of the fact that using the known methods one will only be capable of installing section weights of about 50 to 300 metric tonnes and lengths of 12 to 50 meters depending on the suspension cable strength.

Thus, according to the invention presented herein, a new design, fabrication, erection and assembly method has been developed which in principle allow a ground level and in-house prefabrication of a complete and outfitted suspension bridge girder which may be transported to the erection site in a floating state and then lifted into the span under full control of the suspension cable geometry and forces.

In addition it has been developed a method of installing the bridge girder in long sections without over-stressing the suspension cable or hangers. In both cases, a method of adjusting the length of the hangers has been developed.

The elevation and installation of the bridge girder or the bridge girder sections will preferably be made using hydrau-

lic winches called hydraulic pulling machines, but also other hoisting remedies may be used, like winches etc.

If it is found practical for any reason, also cable cranes, floating cranes, masts or other lifting device may be used, and the bridge girder may be attached to the hanger cables by equipment for compensation of the suspension cable geometry.

For the elevation of the complete bridge girder, the number of pulling machines will be according to the weight of the girder, the accepted change in curvature of the suspension cable over the hanger clamp, and the strength of the girder.

The pulling machines may be positioned on the suspension cable, or hanging down from the hanger clamps. It is also possible to let the pulling machines be connected to the girder or a lifting machine yoke attached to the girder. Climbing cables, which ends has been secured to either the girder or to the lifting cable yoke depending on the position of the pulling machines, will pass through the pulling machines. These wires are called climbing wires, and will normally not be a part of the bridge.

By using the above remedies and the methods described, the bridge girder may be lifted into position in the span.
The pulling machines may be controlled by adjusting the hydraulic pressure which corresponds with the load in the lifting cables, hence the suspension cable geometry.

Further objectives, features and advantages will be presented in the following description and drawings.

Fig. 1-2 demonstrates the commonly used methods of erection of suspension bridges.

Fig. 3-5 demonstrates the detailed geometry problem during lifting of bridge girder elements.

Fig. 6-7	demonstrates the sequences for the erection of a suspension bridge by elevating one continuous girder element according to the invention.
Fig. 8-11	demonstrates the sequence for the erection of a suspension bridge by elevating several long girder elements according to the invention.
Fig. 12	demonstrates schematically the hydraulic system.
Fig. 13	demonstrates alternative 1 of the lifting gear using single lifting machines.
Fig. 14	demonstrates alternative 2 of the lifting gear position using tandem lifting machines.
Fig. 15	demonstrates alternative 3 of the lifting gear position using inverted tandem lifting machines.
Fig. 16	demonstrates alternative 4 of the lifting gear position using inverted tandem lifting machines.

Fig. 1 show the common way of erecting a suspension bridge. The small bridge girder elements 1 are brought to the site by barges 5 and lifted by using a cable crane 2 rolling on the suspension cables 6 and operated by means of cable crane wires and cable crane winches 4 situated at the pylons or on the cable crane itself.

When the first small bridge girder element 1 has been lifted in position and attached to the hangers 15, the next small bridge girder element 1 will be installed in the same manner. The two small bridge girder elements will now be loosely connected by bolts, so that the connection has a freedom to move and bend vertically in relation to each other.

This sequence is repeated until 70% to 75% of the bridge span has been erected. Then the curvature of the suspension cable

6 and the bridge girder has become so close to what has been predetermined, that the welding of the small bridge girder elements may start.

Fig. 2 show the commonly used method of installation by means of a floating crane.

The procedure will be equal to the one described in Fig.1. The disadvantages of using a floating crane, is that its position has to be controlled by using anchors, lines to shore etc. In addition, the position of the crane derrick may create restrictions and risk, in that the crane derrick must reach between the suspension cables, over the suspension cables or under them during the different sequences of lifting.

Fig.3, 4 and 5 show the problem around lifting and installing long bridge girder elements 12.

The suspension cable geometry 6 will be forced to have the correct geometric form, normally a parabola, over the bridge girder element if the hangers 15 are connected to the bridge girder 12. If such an installation is allowed, the curvature of the suspension cable 6 from the hanger clamp 8 to the pylon top will create a vertical force in the lifting cable 17 and the lifting machine 22. In addition to creating a bending moment on the bridge girder 12, the change in angle 16 of the suspension cable may cause overstressing and deformation.

The vertical force in the lifting cable 17 will increase with increasing bridge girder section length up till its maximum at a girder section length about 50 % of the total span width. Then the vertical force start to decrease, and by a girder section length of 100 % of the span length, the force will be equal to the individual hanger loads.

In order to resolve this problem, a system has been invented that compensates for the geometry and force problem by allowing the suspension cable 6 to take a different geometry 33. This is done by paying out on the lifting machines 21, 22 so that the hanger clamp 8 take a new position 19, and the suspension cable get a more soft transition over the outermost hanger clamps 20, 19 and up to the pylon top.
The control of the suspension cable geometry 33 may be done by using distance measuring device, for example wires 29 or tape hanging down from the respective hanger clamps into the sea 31 or down to the ground. At the end of the wires 29 weights 30 may be attached for stabilization and to keep the wires 29 taught.

At the bridge girder, length measuring instruments 34 may be connected, and the distance from the suspension cable 6 down to the bridge girder 12 may be measured.

The method of controlling the compensation on the outermost lifting machines 21, 22 may be performed by using hydraulic pressure valves set for a predetermined maximum pressure, or directly by signals from the distance measuring instruments 34 to solenoid valves controlling the individual lifting on the machines.

In addition to the above method, an angle-measuring instrument may be connected to the hanger clamps 19, 20, and the angle readings or signals used for control of the lifting machines 21, 22.

The above description and sequence makes it possible also to erect very long bridge girder elements in a sequence as described in Fig.8 through 11 , or two and two girder sections simultaneously.

Fig.6 and 7 show the installation of a near complete bridge girder 11.

The long bridge girder shall preferably be fabricated at a yard, and fully outfitted with rails, electric lights, and even pavement. The bridge girder 11 shall preferably be made self floating, so that the transportation to site may be made without using barges. The bending moments created in the bridge girder by the water and the fact that the girder is slightly curved, may be compensated by using ballast at the ends.

The girder 11 shall be brought under the suspension cables, and lifted on wires into its predetermined position in the span.

The hydraulic lifting machines 9, also called linear pulling machines or center hole jacks, may be installed in different manners, on the suspension cables, hanging down from the suspension cables, on the girder, under the girder or even inside the girder.

The lifting cables 10 should preferably be fitted with stabilizing submerged weights.

The girder 11 shall be positioned under the bridge span, the lifting cables 10 attached to the lifting machines 9, and made taught by using the machines.

At this stage, the individual loads on the pulling machines and the geometry control instrumentation will be set in reference position.

For the 75% to 100 % girder, the pulling machines load may be set equal, and all machines hooked up to the same hydraulic line.

The lifting process start by lifting the girder 11 out of the water. During this part of the lifting process, it is

important to let air enter under the girder in a controlled way, and to reduce the forces imposed by wave movements. Therefore, it is advised to start lifting the girder 11 in a slightly tilted position.

At an elevation of 1-2 meters above the water, the girder 11 may be made horizontal. From this position on and up, the lifting shall be performed by a synchronous operation of the pulling machines.

Lifting the girder 11 into position in this manner, will put an even load on the lifting machines 9 provided the lifting machines are controlled, and are working synchronous.
This may be achieved by making even, or controlling the hydraulic pressure in the machines, or by using the readings from the geometry monitoring instruments 34.

When the girder reaches its final position, the hanger cables 15 will be connected, and the lifting machines 9 and the lifting cables 10 removed.

The dilatation elements may be lifted in position using the above described method, and finally connected to the girder and to the ramp by welding and bolting.

Fig. 8, 9, 10 and 11 show the erection of a bridge consisting of prefabricated long bridge girder elements 12, 13, 14.

The bridge girder elements 12, 13, 14 etc. will be prefabricated and outfitted in a yard. They will be brought to the building site floating or on barges, and positioned under the suspension cables 6.

As with the full-length girder 11, the sections 12, 13, 14 will be prefabricated and brought under the bridge span. The start of the lifting sequence will be as described for the full-length girder.

The difference in method of installation is related to the balance between suspension cable geometry and the stress in the outermost hanger cables.

The center element 12 should preferably be installed first.

Before the lifting takes place, the outermost lifting machines 21, 22 shall be set to control the maximum forces in the hangers, thereby also controlling the suspension cable geometry.

During the lifting of the girder element 12, the change in geometry over the outer hanger clamp will be made smooth by the lifting machines 21, 22.

After lifting the first section 12 to its correct elevation, only the hangers 15 in the uncompensated zone will be connected to the girder element 12. The compensating lifting machines 21, 22 will remain in position.

In the next sequence, it is advised to lift the second element 13 and third girder element 14 simultaneously, thereby maintaining a central load on the suspension cables.

In order to make the elevation simultaneous, the lifting machines 9 lifting the two sections, shall communicate through a hydraulic line, an electric cable or radio link. During the start of the lifting process, the compensating lifting machines 21, 22 for the central girder section 12 already in position, will now pull down the suspension cable 6 as the load is partially taken over by the lifting machines 9 elevating the two girder elements 13, 14.

When the elements 13, 14 arrives at their final position, the hangers 15 are attached to the girders 13, 14 part from

the outermost hangers, where the lifting machines are compensating the forces.

The machines compensating for the forces in the hangers of the central girder element will remain in position until the next two girder sections have been installed.

The above sequence will be repeated until all the girder sections are elevated and connected to the hanger cables.

Fig.12 show a simplified diagram of the hydraulic system. The lifting machines 9 are connected to the suspension cables 6 via the lifting cables 10. The hydraulic power package 26 will normally consist of a tank for hydraulic oil 27, and one or more hydraulic pumps 28 providing hydraulic pressure to the lifting machines via hydraulic lines.

The pressure measuring instruments, the pressure regulating valves, the control valves, and position locking valves and the direction control valves for the machines has not been shown, as these valves will vary with the different types of machines.

Fig. 13 show a simple way of hanging up the lifting machines. The cable solution shown 6, 8 is called an "open" cable, but the same type of arrangement may be applied on the "closed" types of suspension cables.

This method of fitting the equipment is meant for the lighter types of bridges, where the capacity of the lifting machine 9 makes it possible to use only every second hanger clamp 8 for lifting, and the rest for connecting the hangers to the bridge girder 12.
The lifting machine 9 is hanging down from the hanger clamp 8, and is lifting the bridge girder 12 by the lifting cable 10 and the terminal 25.

Fig.14 show lifting by tandem lifting machines 9 connected to a lifting machine yoke 23 positioned over the hanger clamp 8.

The lifting machines 9 are lifting the girder 12 by the lifting cables 10 connected to a lifting cable yoke 24 connected to the upper hanger 15 via its terminal.

Fig. 15 show lifting by reversed tandem machines 9 connected to a lifting machine yoke 23 which in turn is connected to the lifting ear of the bridge girder 12.

The upper end of the lifting cables 10 is connected to a cable yoke 24 positioned over the hanger clamp 8.

Fig. 16 show lifting by reversed tandem machines 9 connected to a lifting machine yoke 23 which in turn is connected to the lifting ear of the bridge girder 12.

The upper end of the lifting cables 10 is connected to a lifting cable yoke 24 which is clamped to the hanger cable 15 by bolts 36 and a distance piece 35 to allow the hanger terminal to reach down to the lifting ear on the bridge girder 12.

Also other arrangements of various types of lifting devices may be made. The lifting device may be arranged on, or at the suspension cables, under the bridge girder element or inside the element, and may consist of ordinary cable winches, climbing machines, hydraulic jacking systems with bolts or tube pieces in stead of cables.

Of utmost importance is the ability to fully control the forces and the geometry of the suspension cables and the bridge girder and girder elements during erection and installation.

PATENT CLAIMS:

1.
A method for constructing and assembling of a suspension bridge with main girder of steel, aluminium or concrete (11) suspended by hanger cables or hanger rods (15) from suspension cables or suspension rods (6),
c h a r a c t e r i z e d b y the fact that the bridge girder is fabricated in one piece or in bridge girder elements larger than the distance between two hanger cables or hanger rods (15), that the bridge girder (11) is brought and positioned under the suspension cables (6) at surface level and elevated in a controlled manner into the bridge span to its final elevated position, and that the bridge girder (11) is locked to the hanger cables or hanger rods (15).

2.
A method according to claim 1,
c h a r a c t e r i z e d b y the fact that the respective bridge girder elements (12,13,14) are elevated in a sequence, preferably starting with the central girder element (12) thereafter the girder element (13) on one side of the central element (12) then the girder element (14) on the opposite side of the central element (12) and so on until all the girder elements are elevated and installed by connecting one to the other until the complete bridge span has been completed.

3.
A method according to claim 1,
c h a r a c t e r i z e d b y the fact that the respective bridge girder elements (12,13,14) are elevated in a sequence, preferably starting with the central girder element (12) thereafter simultaneously the two girder elements (13,14) on both sides of the central element (12) and so on until all the girder elements are elevated and

installed by connecting one to the other until the complete bridge span has been completed.

4.
A method according to claim 2 or 3, c h a r a c t e r i z e d b y the fact that the number of bridge girder elements is an uneven number.

5.
A method according to claim 1 - 4, c h a r a c t e r i z e d b y the fact that at least 4 hanger cables or hanger rods (15) connected to the suspension cables (6) are extended to the water surface (31) or ground surface in order to form lifting or climbing cables or rods (10) to be used for the elevation of the full bridge girder (11) or the girder elements (12,13,14).

6.
A method according to claim 5, c h a r a c t e r i z e d b y the fact that the climbing or lifting cables or rods (10) are separate units for temporarily or permanently connection to the respective hanger cables or hanger rods (10), direct to or over the hanger clamp (8), or to the suspension cables (6).

7.
A method according to claim 1 - 6, c h a r a c t e r i z e d by the fact that the bridge girder or girder elements (11,12,13,14) are elevated using hydraulic lifting or climbing machines or winches (9).

8.
A method according to claim 7, c h a r a c t e r i z e d by the fact that the lifting or climbing machines (9) are controlled by the tension in the lifting or climbing cables or rods (10) and/or the distance between the upper and lower connection point of the lifting

or climbing cables or rods (10) and/or the geometry of the suspension cables (6) and/or the change in angle of direction of the suspension cables (6) over the hanger clamps (8) in that the monitoring and control may be performed manually or automatically or a combination thereof.

9.
A method according to claim 7 or 8,
c h a r a c t e r i z e d b y the fact that the individual hanger cables or rods (10) may be adjustable by using hydraulic lifting or climbing machines or winches or actuators (9) in order to adjust the bridge girder (11) to its correct geometric form or positioning the individual bridge girder elements (12,13,14) in order to connect them to each other successively or after the complete span has been erected and the suspension cables (6) have been adjusted.

10.
A method according to claim 7 - 9,
c h a r a c t e r i z e d b y the fact that the climbing or lifting machines or winches are positioned at the bridge girder (11) or girder elements (12,13,14) alternatively by the suspension cables (6).

11.
A method according to claim 8,
c h a r a c t e r i z e d b y the fact that monitoring and control of the elevation is made by the use of electrical signals or hydraulic pressure from load cells or from the lifting or climbing machines (9) at the respective lifting or climbing cables (10).

Fig. 1

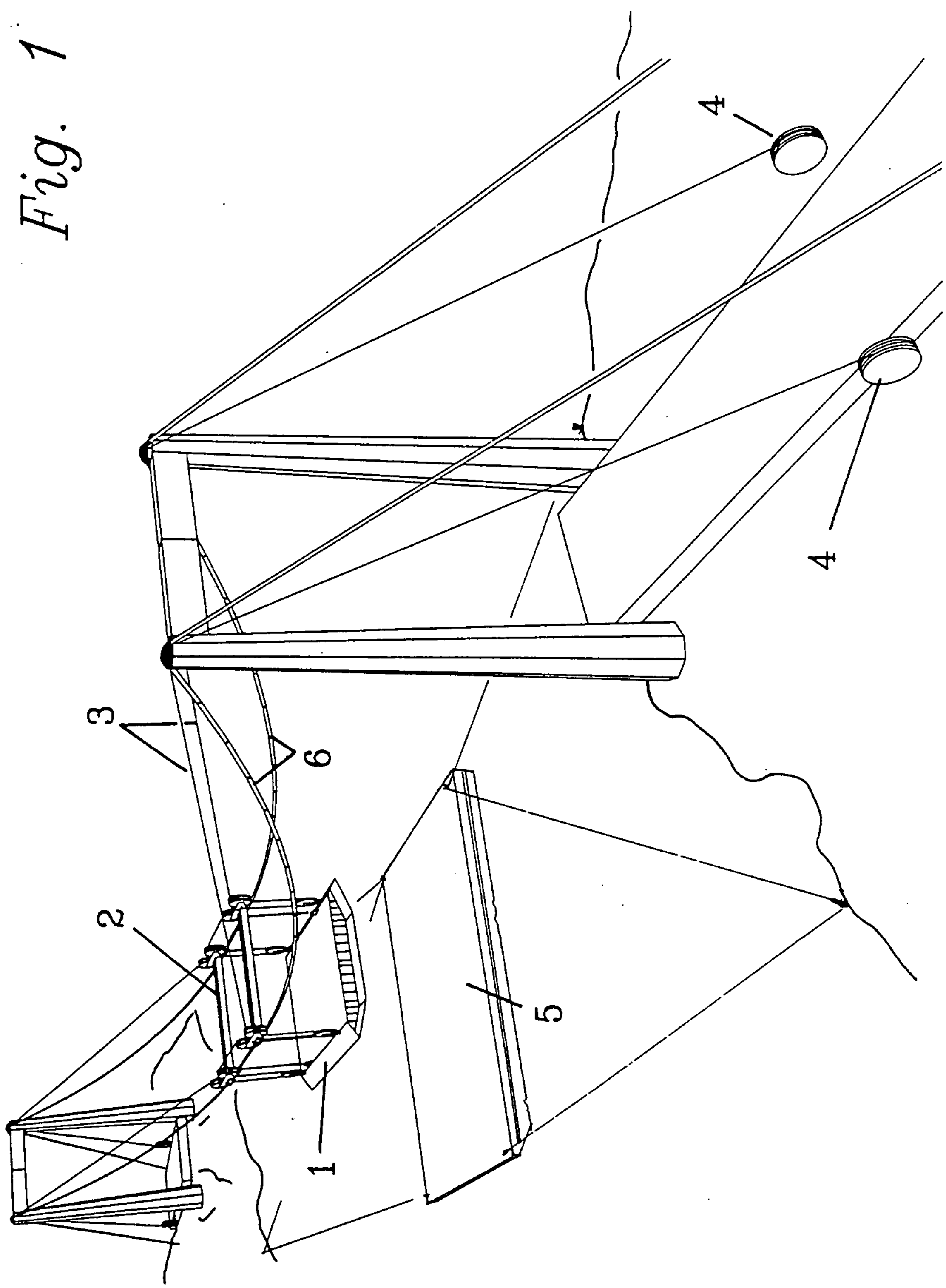


Fig. 2

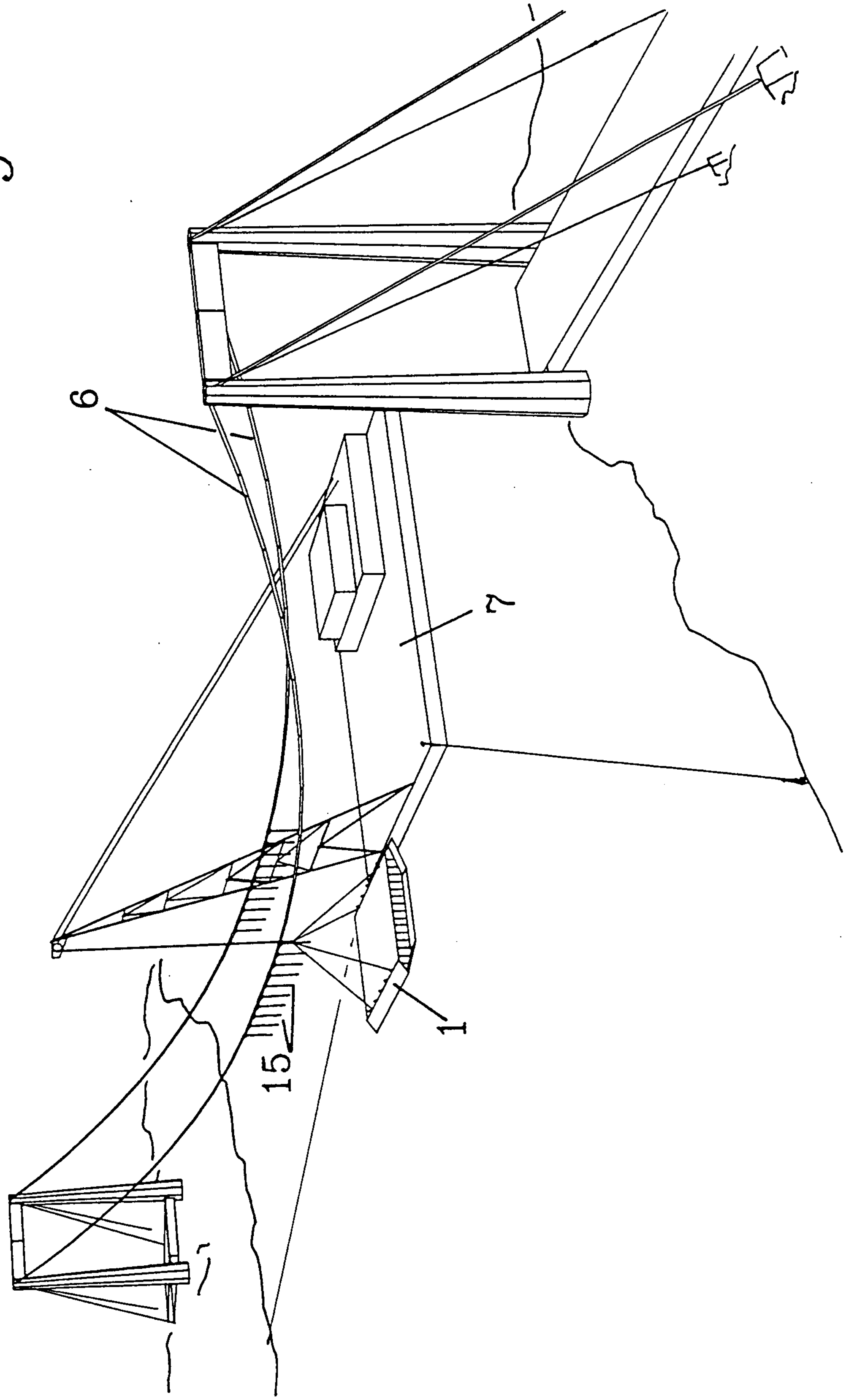


Fig. 3

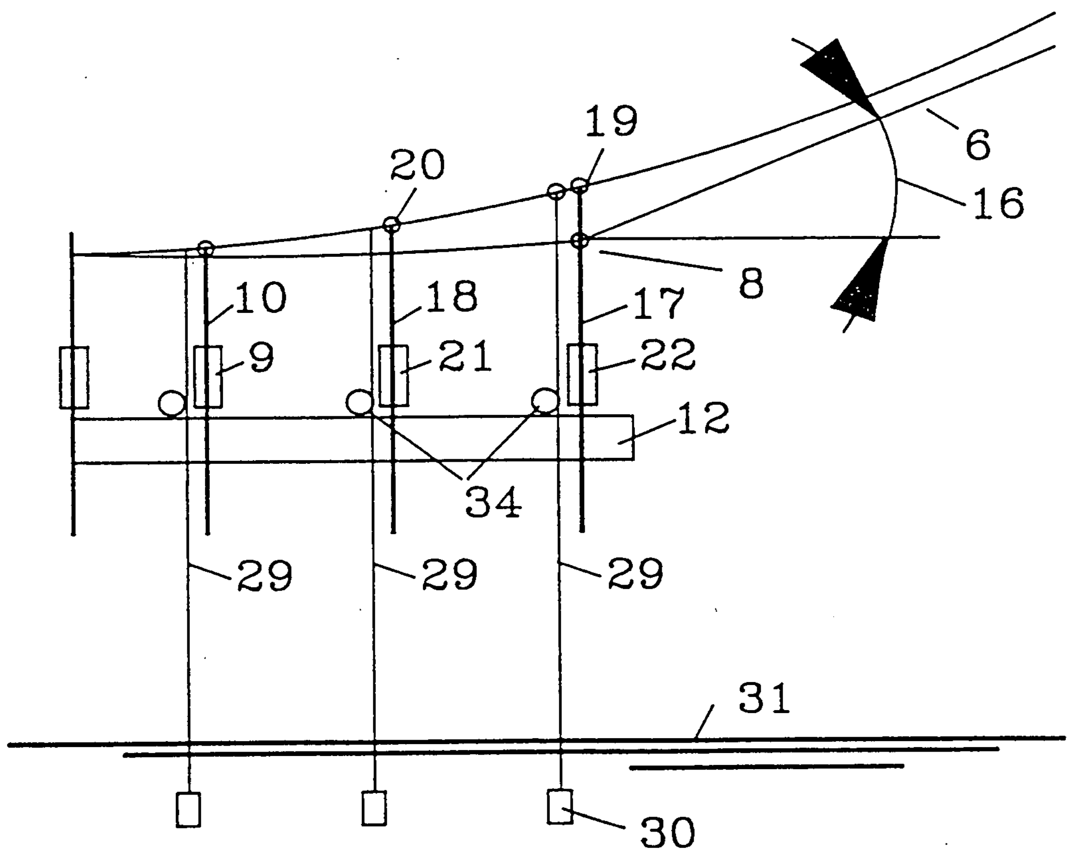


Fig. 4

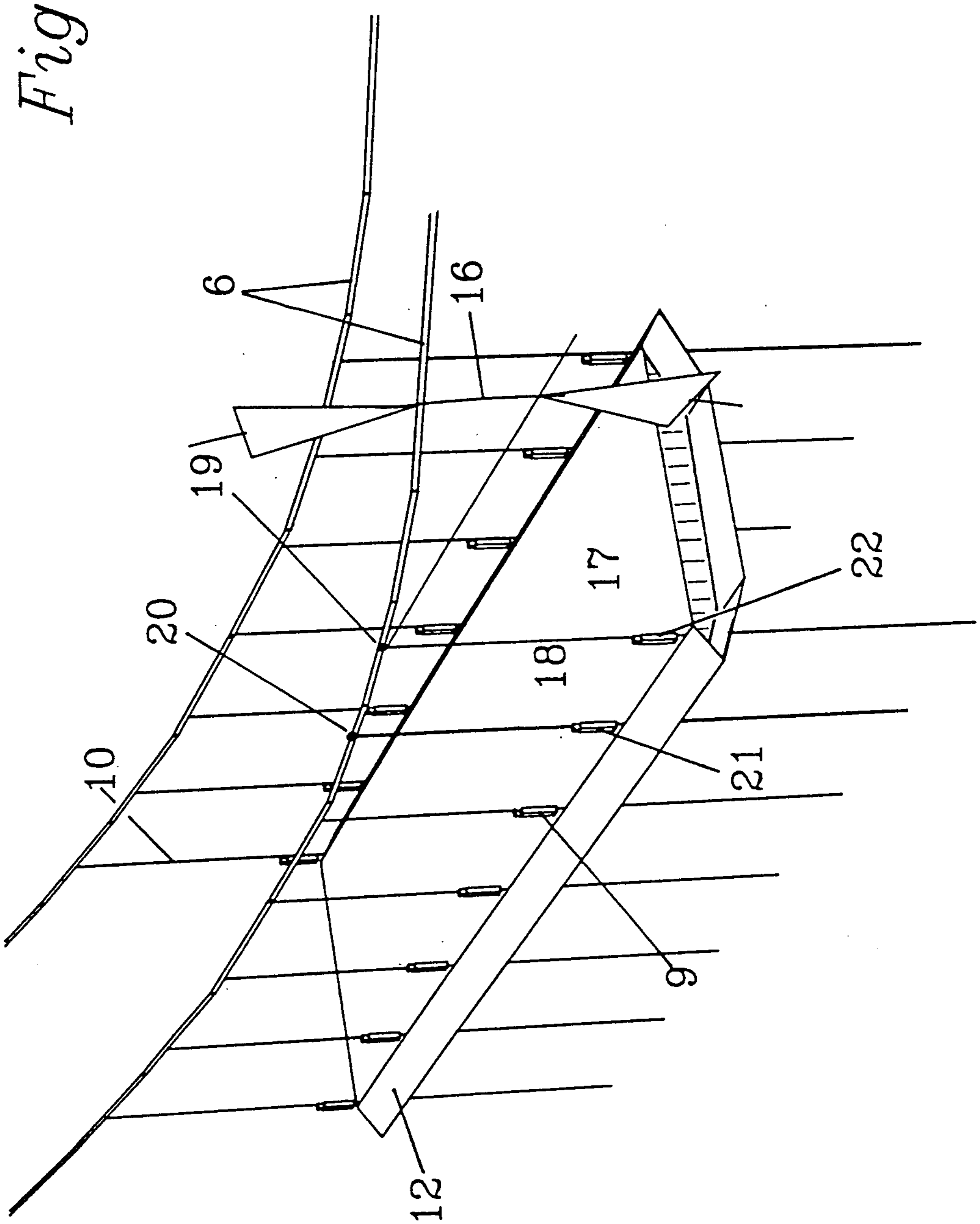
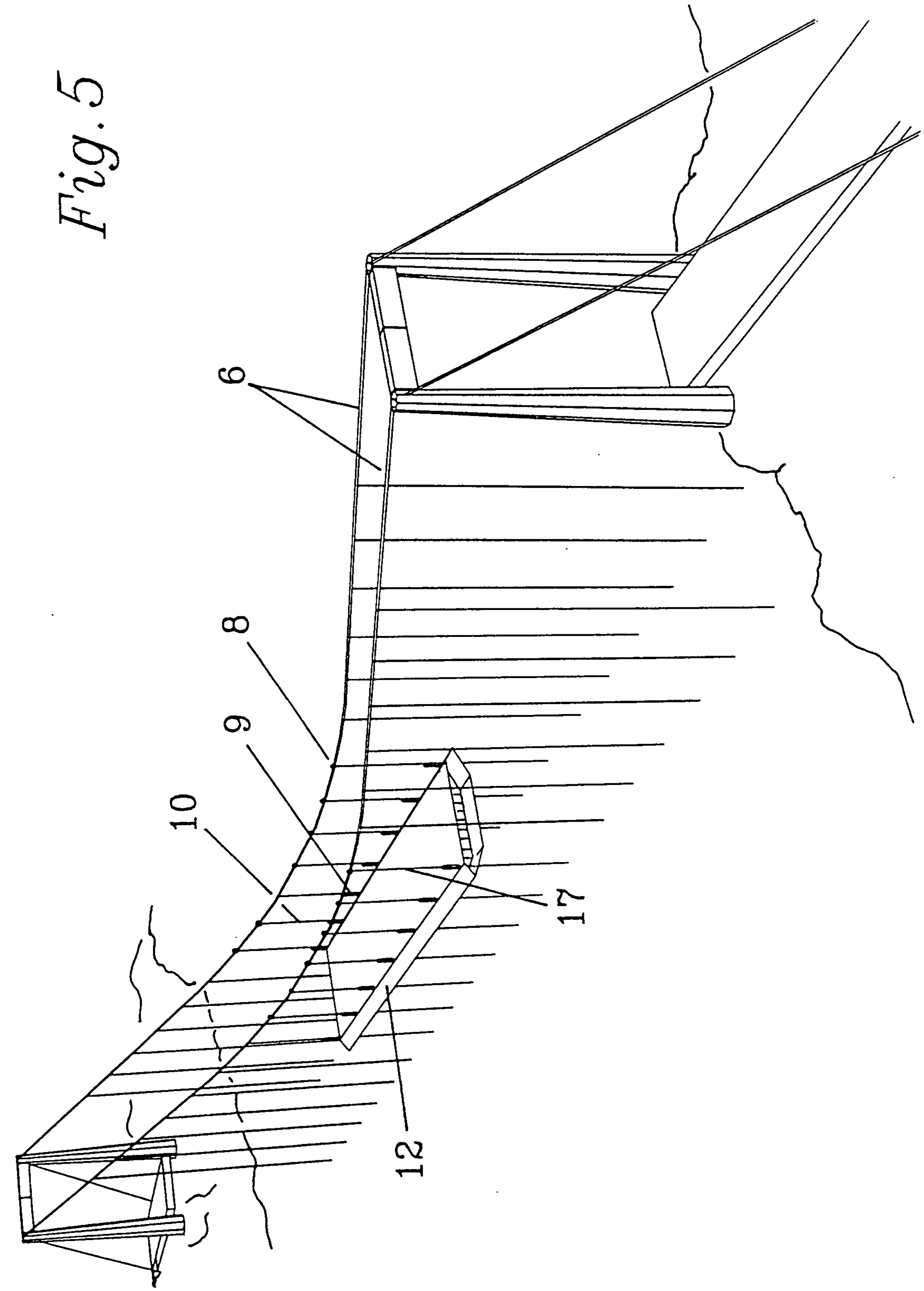


Fig. 5



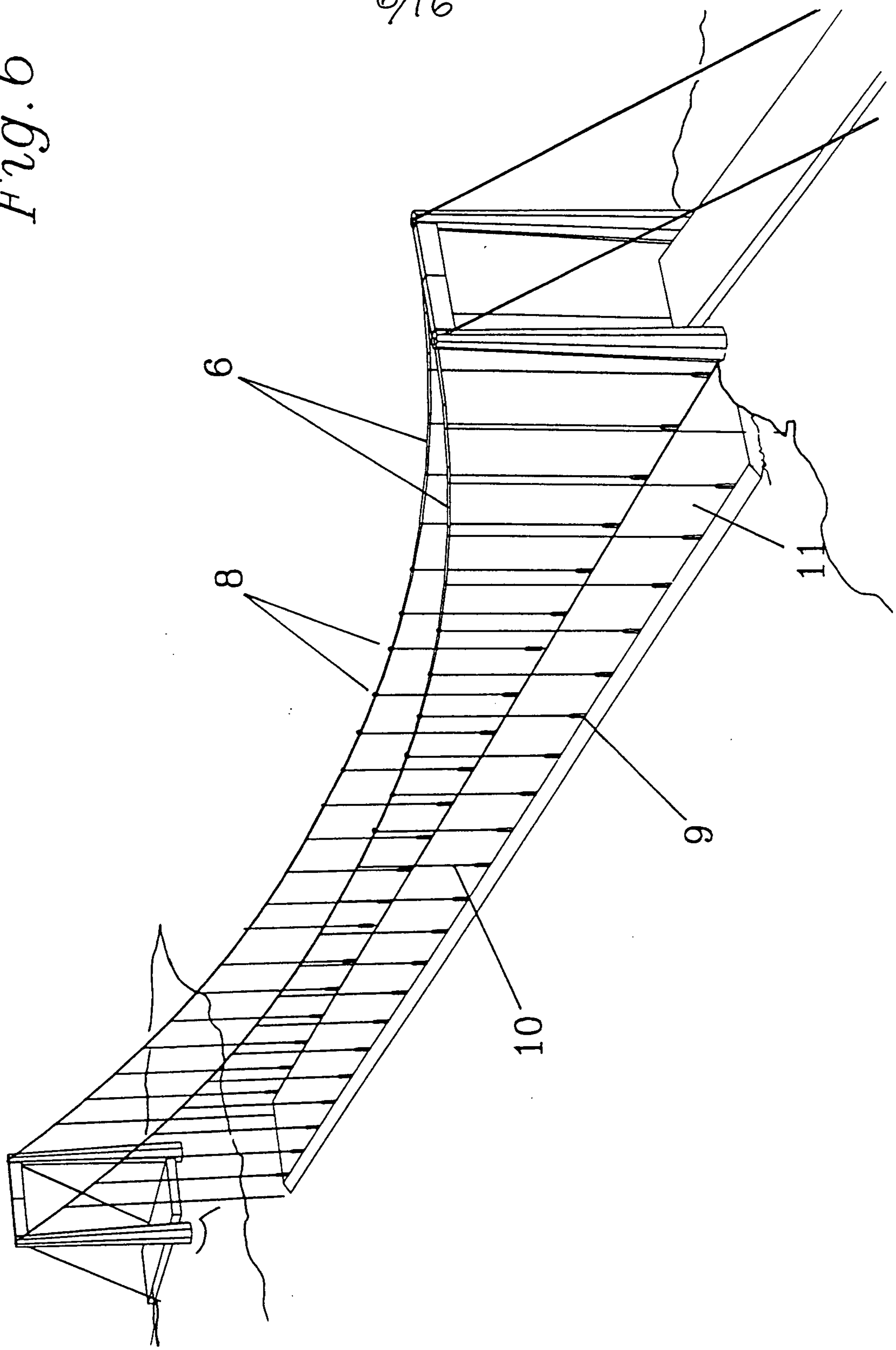
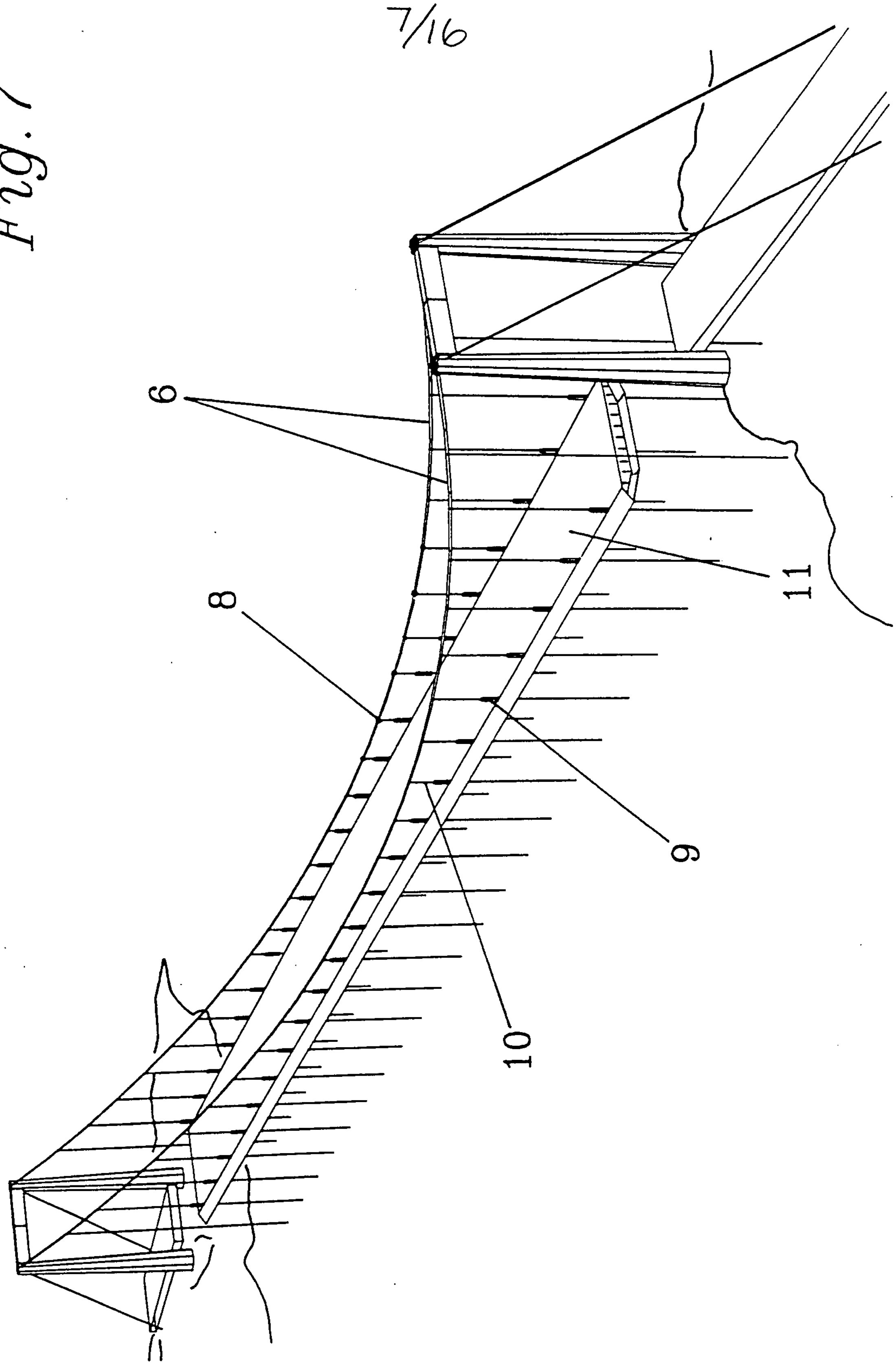


Fig. 6

Fig. 7



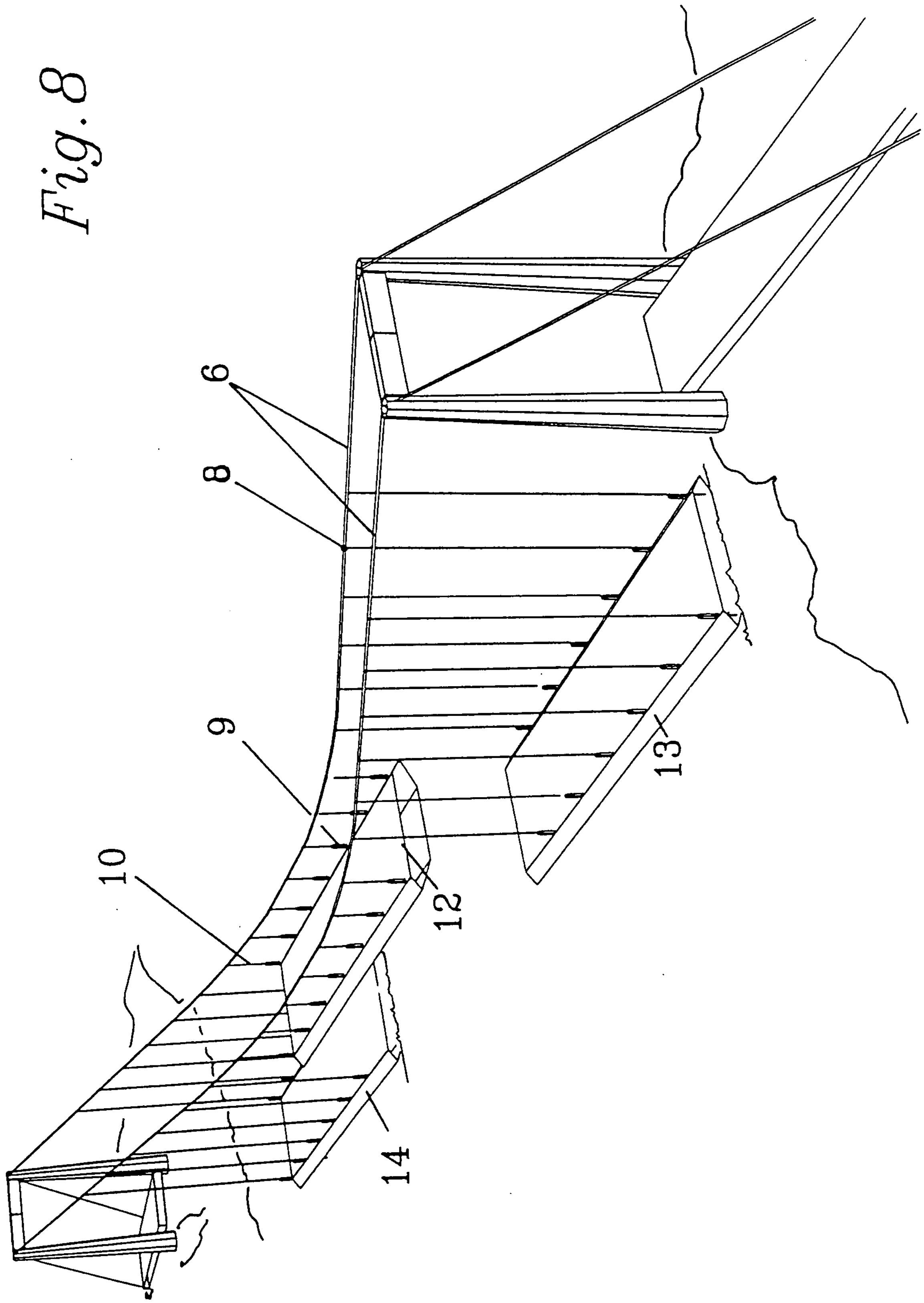


Fig. 8

Fig. 9

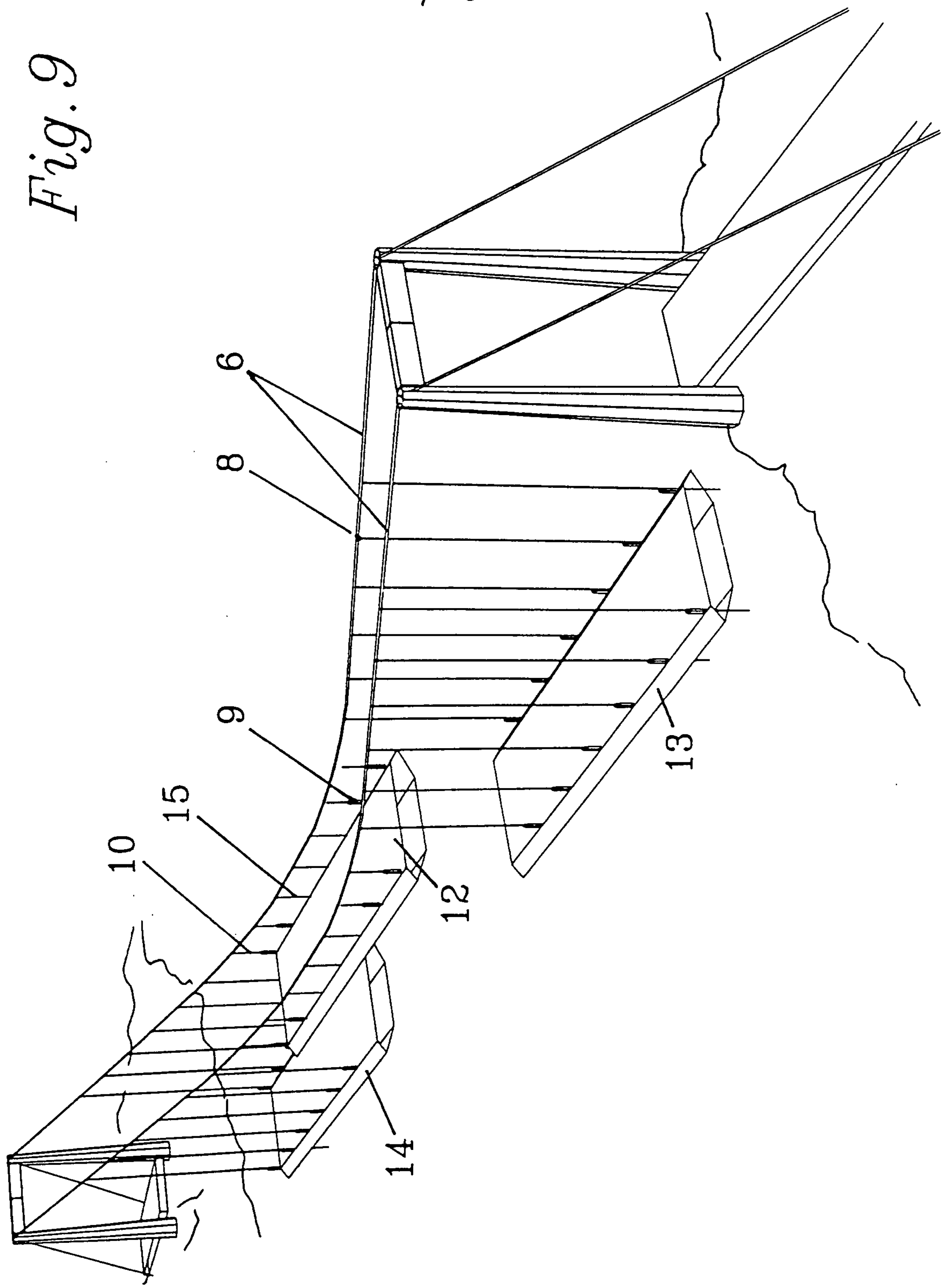


Fig. 10

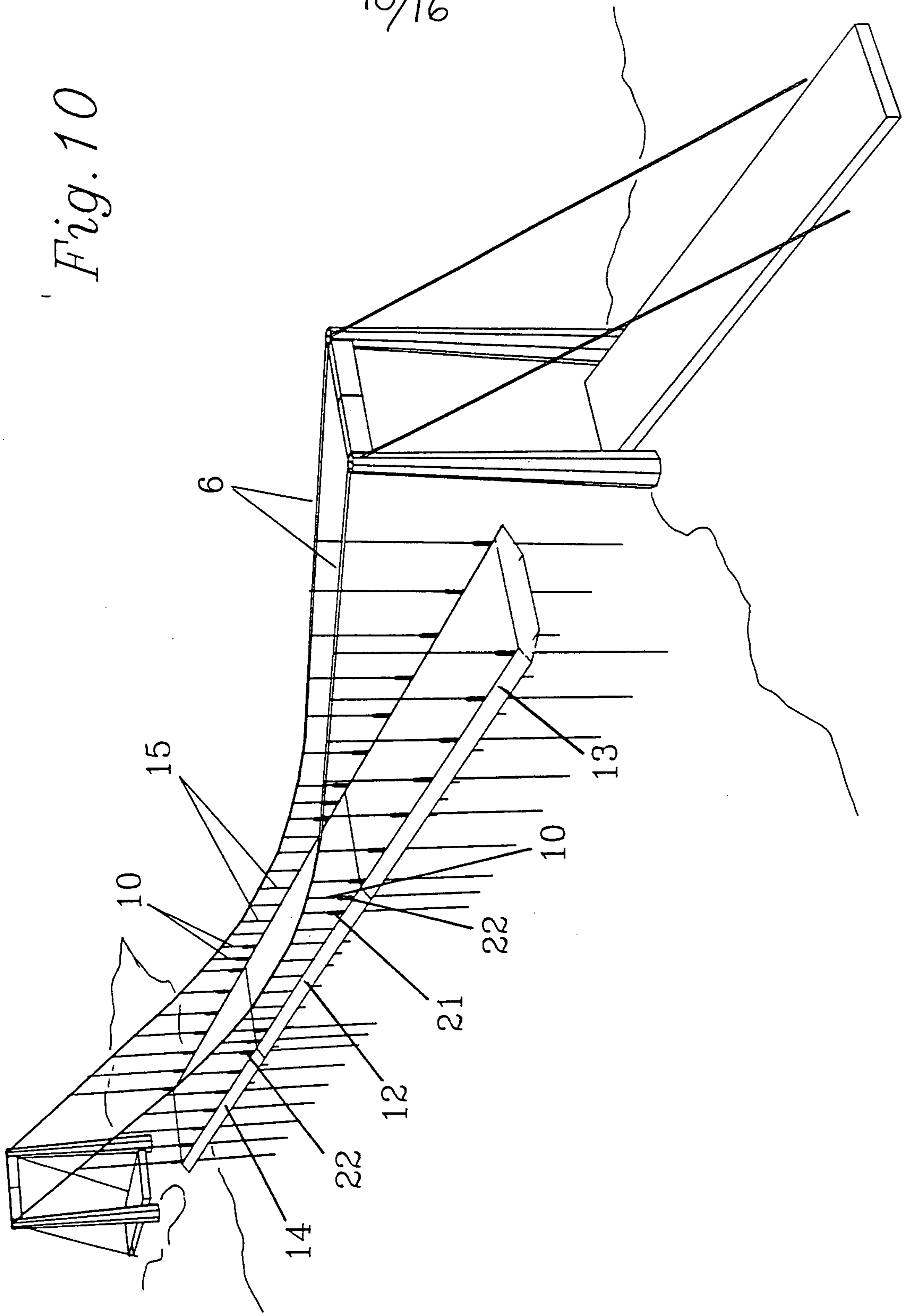


Fig. 11

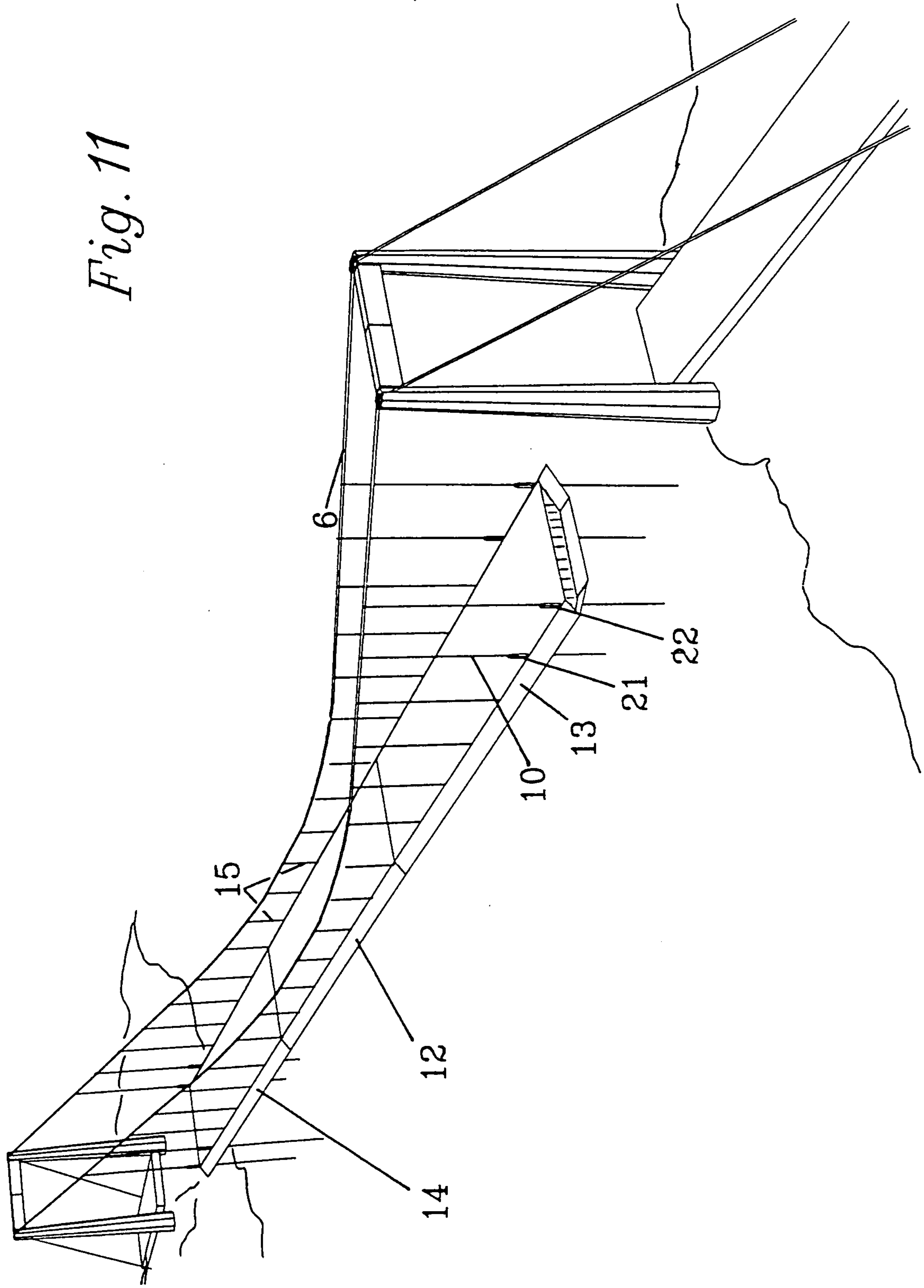


Fig. 12

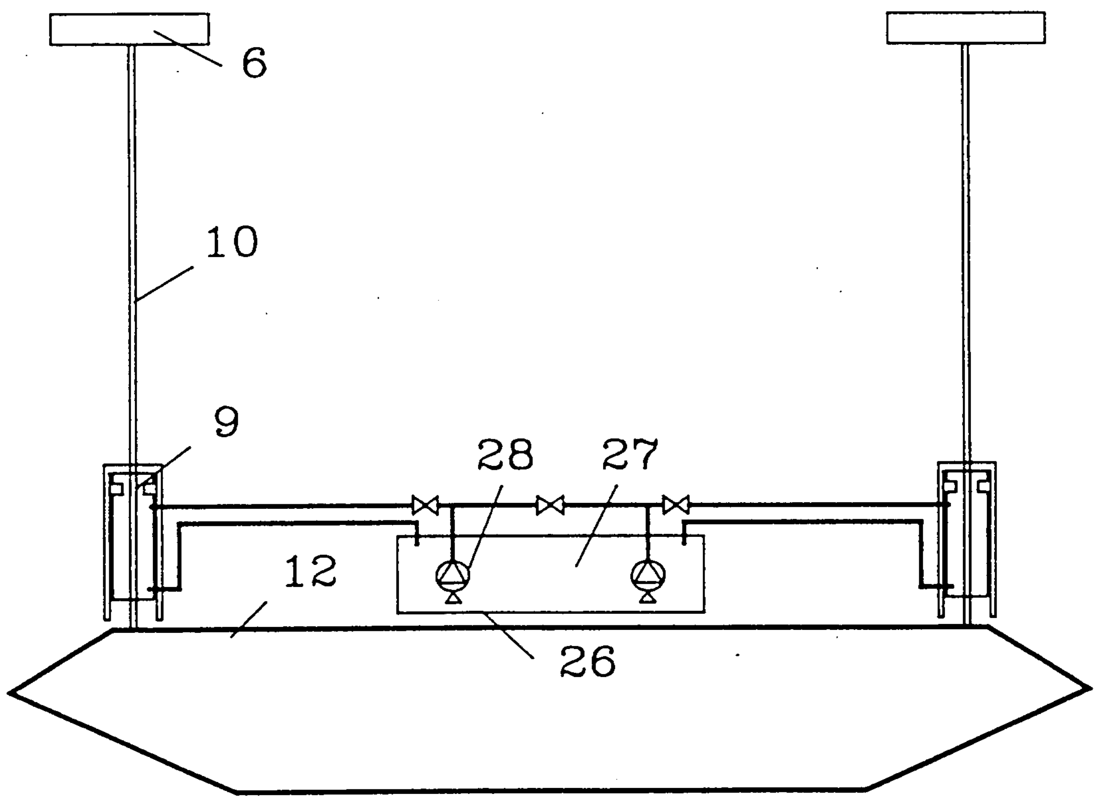


Fig. 13

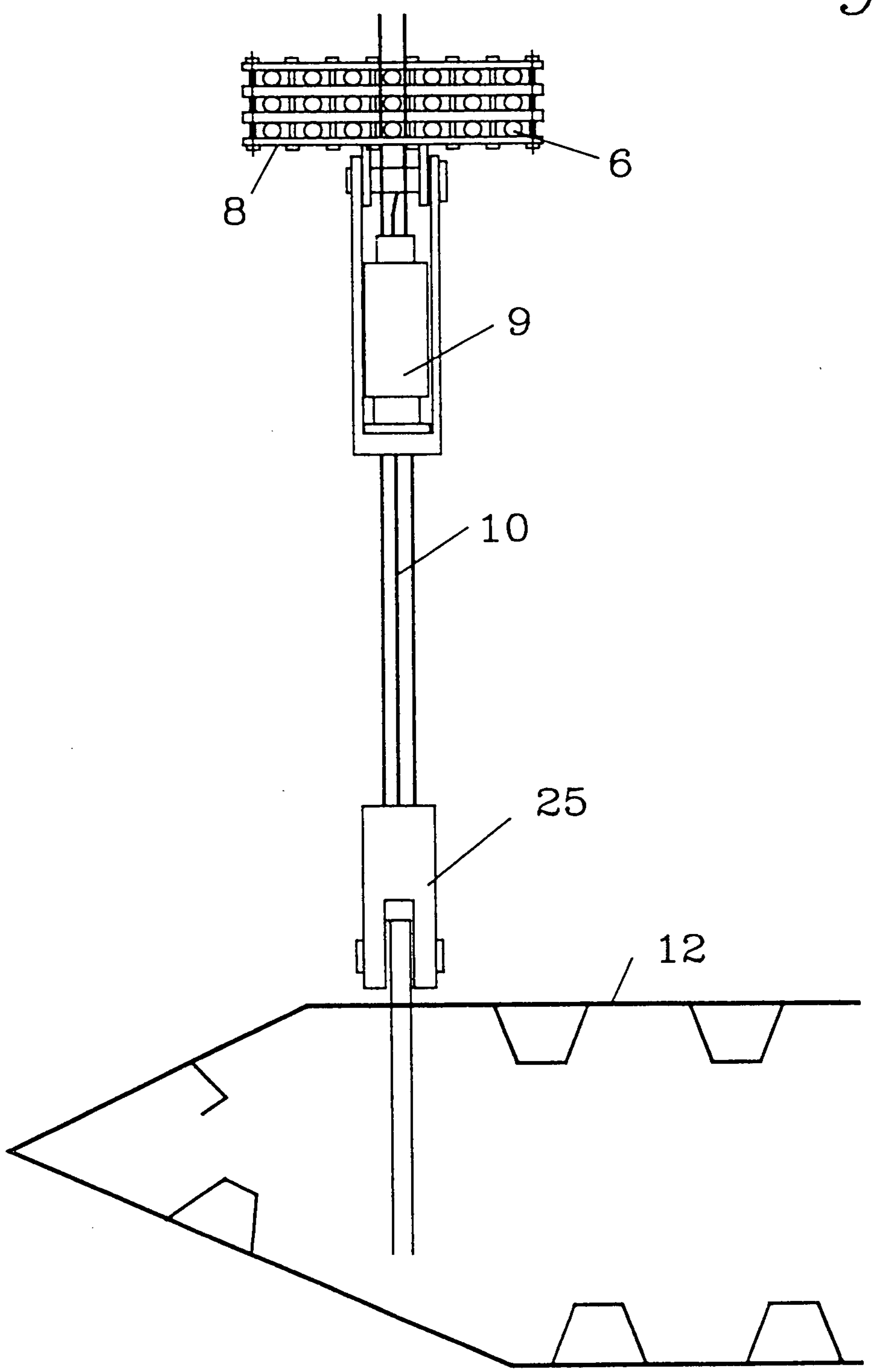


Fig. 14

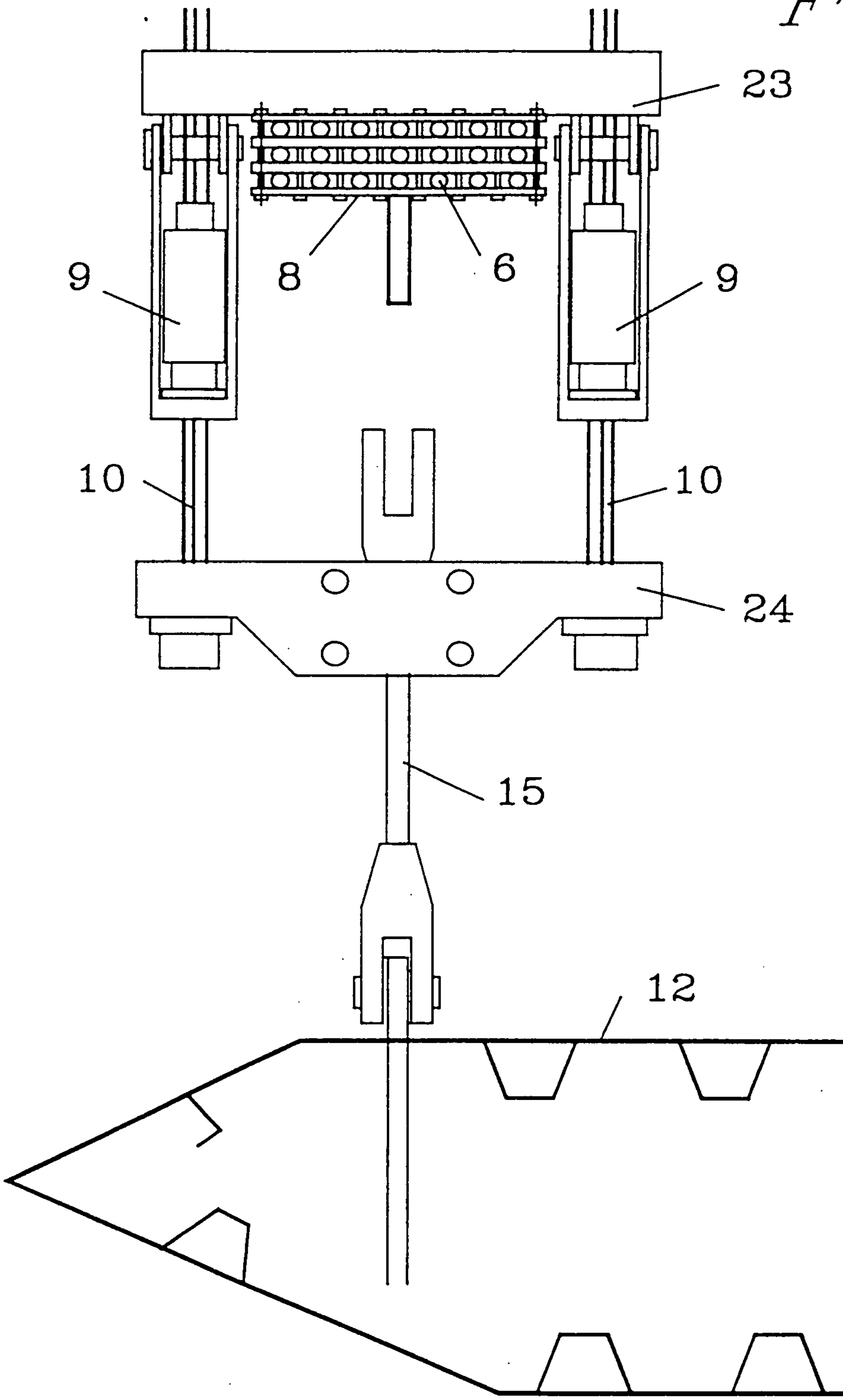


Fig. 15

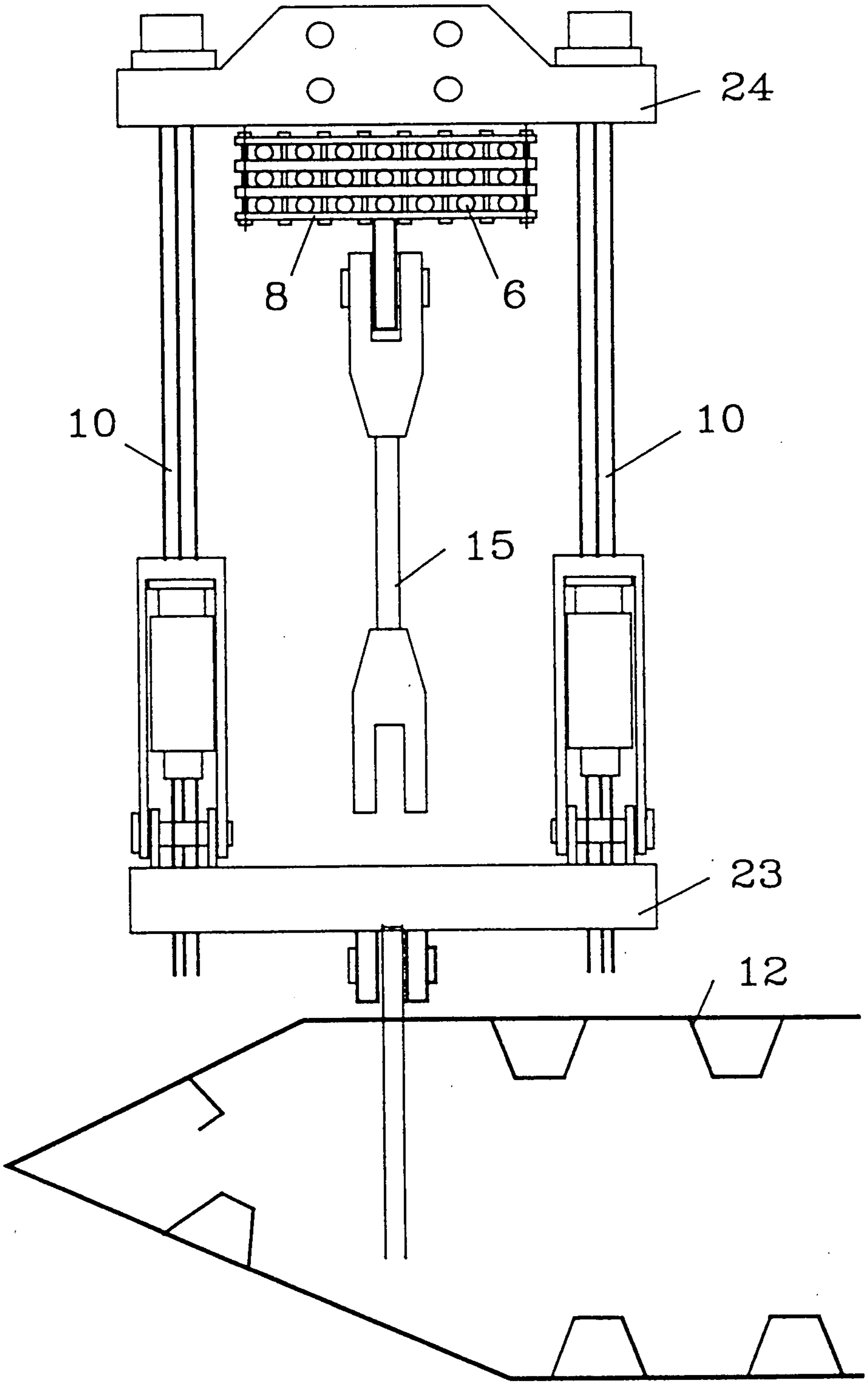


Fig. 16